Saskatchewan
Research Council

AN ASSESSMENT OF GROUND DEPOSITS FROM AERIAL SPRAY OPERATIONS IN THE KAMLOOPS FOREST REGION OF BRITISH COLUMBIA

by

K. Wallace
R. Jahren

SRC Technical Report No. 200

Publication E-906-1-B-88 January, 1988

AN ASSESSMENT OF GROUND DEPOSITS FROM AERIAL SPRAY OPERATIONS IN THE KAMLOOPS FOREST REGION OF BRITISH COLUMBIA

by

K. Wallace
R. Jahren

SRC Technical Report No. 200

SRC Publication No. E-906-1-B-88

January, 1988

SUMMARY

Eight sets of Kromekote deposit cards and one set of water sensitive paper were analyzed for VMD, NMD and coverage. The VMD, NMD and number of drops per cm^2 were all lower, compared to the 1986 data. The decreased application rate of 2.8 to 3.1 L/ha and increased flying height accounted for the difference. The addition of a fluorescent dye to the tank mix allowed determination of deposit densities from petri dishes. The coefficient of variation in the deposit for two spray sites was 39% and 82%. Alternative methods for assessing deposit are discussed; passive samplers, e.g. wire or plastic tubing, and active samplers such as the rotorod. Droplets in the size range of 30 to 50 um have the highest collective efficiency on needles and buds. A fixed wing aircraft using rotary cage atomizers spraying during times of light winds (1 to 3 m/sec) will disperse the droplets into the canopy by turbulence rather than sedimentation. The rotary cage atomizers had a high percent of droplets in the 30 to 50 um range when operated at high r.p.m.

ACKNOWLEDGEMENTS

The authors would like to thank Dr. R.F. DeBoo, Manager, Pest Management (Protection Branch) and Mr. S. Taylor, Pest Management Technician for their assistance and support in the production of this report. The support of Dr. Ron Edwards, Pest Management Coordinator, Kamloops Forest Region, is appreciated in allowing us to cite their 1987 report as a reference. We are grateful to Dr. R. Grover of Agriculture Canada for use of his Quantimet system. The following Saskatchewan Research Council (SRC) staff are recognized for their assistance: Dr. J. Maybank for review, and Miss D. Diduck for typing the manuscript.

TABLE OF CONTENTS

	Page
SUMMARY	i
ACKNOWLEDGEMENTS	ii
LIST OF TABLES	iv
LIST OF FIGURES	v
INTRODUCTION	1
MATERIALS AND METHODS	3
RESULTS	10
DISCUSSION	25
RECOMMENDATIONS	28
REFERENCES	29
APPENDIX I - RAW COUNT DATA	30

LIST OF TABLES

Table		Page
1	Sample Analysis and Identification	4
2	Aircraft and Meteorological Parameters	6
3	Droplet Size Data (Kromekote Cards)	11
4	Petri Dish Analysis	12
5	Spray Image Set A - Dewdrop Calibration	15
6	Spray Image Set B - Dewdrop Kromekote Cards	16
7	Spray Image Set B - Water Sensitive Paper	17
8	Spray Image Set C - Orchard Lake	18
9	Spray Image Set D - Mt. Godreau	19
10	Spray Image Set E - Paul Lake	20
11	Spray Image Set F - Moulton Creek	21
12	Spray Image Set G - Coyote Lake	22
13	Petri Dish Analysis Dewdrop Range	23
14	Petri Dish Analysis Coyote Lake	24

LIST OF FIGURES

Figure		Page
1	Set A - Ag. Truck - Micronair AU5000	14
2	Drop Distribution Dewdrop Calibration Run	15
3	Drop Distribution Dewdrop Calibration Run Kromekote Cards	16
4	Drop Distribution Dewdrop Calibration Run Water Sensitive Paper	17
5	Drop Distribution Orchard Lake	18
6	Drop Distribution Mt. Godreau	19
7	Drop Distribution Paul Lake	20
8	Drop Distribution Moulton Creek	21
9	Drop Distribution Coyote Lake	22

INTRODUCTION

Over the past several years the Kamloops forest region has faced a problem regarding defoliation of Douglas fir needles by the western spruce budworm (Choristoneura occidentalis Freeman). In order to gain more information on control of the western spruce budworm, a program of aerial spraying was initiated in 1986.

Due to environmental concerns a formulation of Bacillus thuringensis (B.t.) was selected as the biological insecticide. B.t. was chosen due to its low toxicity to mammals and fish; as well, the compound is very selective to a small number of insects. The disadvantages of B.t. compared to a chemical insecticide are: short persistence on foliage (two to five days), and the mode of action is through ingestion (i.e. a stomach poison) versus contact (chemical insecticide). The insect mortality is usually not as high with B.t. compared to chemical insecticides (Maclauchlan et al. 1987).

One of the major problems in the 1987 spray program was the timing of bud flushing in the Douglas fir trees. The western spruce budworm larvae emerge in May and tunnel into new buds, and as the buds flush the caterpillars feed on the developing buds for approximately six weeks. Since the bud flushing is dependent on sunlight and warmth the same tree could have a two week interval between flushing on the crown compared to the mid-level. Needless to say, this plays havoc with a spray program, as multiple applications may be necessary to control the insect.

The Saskatchewan Research Council (SRC) was contracted by the British Columbia Ministry of Forests, Protection Branch, to measure the deposit from some 40 Kromekote cards and petri dishes providing analysis on cover density (number of drops per cm^2) and deposit density (Billion

International Units [BIU] of B.t. per m^2). The results of the 1987 spray trials are to be compared with the 1986 results (Wallace and Jahren 1987) and, where necessary, alternative sampling procedures will be recommended.

It is known that droplets of 30 to 50 um impact on the buds, larvae and needles with the highest efficiency (Barry et al. 1977; Joyce and Spillman 1979). One such type of nozzle used in aerial spraying capable of giving a high proportion of droplets in this size range is the rotary cage atomizer. The present study utilizes the Micronair AU5000, a smaller and lighter version of the old Micronair AU3000 used in the 1986 study. Measurements of the drop distribution using a Micronair AU3000 showed 67% of the drops were below 50 um in diameter, and the corresponding VMD of the spray was 158.5 um (Joyce and Spillman 1979).

Samples from five different spray blocks in the Kamloops forest region were submitted for analysis. The five spray blocks ranged in size from 72 to 200 ha and encompassed a total of 546 ha.

MATERIALS AND METHODS

Seven sets of Rhodamine B (0.02% in spray mix) dyed Kromekote cards, and one set of water sensitive paper cards were analyzed for cover and deposit density. Two sets of petri dishes were analyzed for deposit density using the fluorescent Rhodamine B dye as a tracer. Table 1 gives information on the location, number, and type of samples put out in the field. All samples were located at ground level in open areas within the Kamloops forest region. The calibration runs were performed on an open field bordering the forest area.

Set A consisted of 23 Kromekote cards set out 2.5 m apart in a line perpendicular to the flight direction. The distribution across the swath in terms of drops per cm^2 could be evaluated using such a layout. Set B comprised three Kromekote cards and three water sensitive cards. The cards were used to access the two surfaces for collection efficiency and stain formation. Both sets were laid out in the Dewdrop Range calibration site.

Sets C through G consisted of three to five Kromekote cards laid out in five different spray blocks during the actual spray runs (Table 1). Each card set consisted of ten cards of which three to five were selected as representative samples. The cards were located in open areas of the forest. The canopy would have filtered the smaller sizes (<50 cm) leaving only the larger drops to impact on the cards.

Sets H and I were composed of 24 and 18 plastic petri dishes (nominal size 100 mm diameter, 15 mm in height) respectively. The dishes were spaced 5 m apart, three in a row, with row spacing 5 m, hence, a rectangular grid was formed. The middle row was parallel to the centre line of the aircraft.

Table 1. Sample Analysis and Identification.

Set	Location	Type of Sample*	Number Analyzed	Spray Operation
A	Dewdrop Range	KC	23	Calibration runs
B	Dewdrop Range	KC and WC	3 of each	Calibration runs
C	Orchard Lake	KC	5	Active spray site
D	Mt. Godreau	KC	4	Active spray site
E	Paul Lake	KC	3	Active spray site
F	Moulton Creek	KC	3	Active spray site
G	Coyote Lake	KC	3	Active spray site
H	Dewdrop Range	PD	24	Calibration runs
I	Coyote Lake	PD	18	Active spray site

*KC = Kromekote cards; WC = water sensitive cards; PD = petri dishes (disposable, 8.8 cm diameter).

The aircraft consisted of a Cessna Ag. Truck equipped with Micronair AU5000 rotary cage atomizers. The aircraft flew approximately 15 to 20 m above the forest canopy (which extended up to approximately 25 m), therefore the average height above ground would be in the order of 40 to 45 m. The application rate was set at either 2.8 or 3.1 L/ha and aircraft speed was held constant at 179 km/hr. The spray pressure at the nozzles ranged from 140 to 210 kPa.

The B.t. formulation used was Futura, which consisted of 14.3 BIU/L. Rhodamine B, which served as a fluorescent tracer, was added to the tank mix normally at a concentration of 0.02% by weight. The potency of the B.t. formulation was checked and a product analysis showed 11,536 I.U. of B.t. were present per milligram of product, this translates to 13.7 BIU/L. The Futura formulation of B.t. resembled a thick paint, this resulted in a decreased flow through the variable restrictor unit on the Micronair AU5000 nozzle. In order to achieve the proper flow it was necessary to drill out the orifice, located in the body of the nozzle.

Meteorological conditions during the tests can be summarized in the following way: winds were calm to very light (4.7 km/hr maximum), the relative humidity was generally high (ranging from a low of 58% to 100%), and the air temperatures were relatively cool (ranging from 5°C to 14°C). The time of spray was generally in the early morning (0500 to 0840), indicative of a stable air condition with a minimum of turbulence. Table 2 shows a compilation of the aircraft and meteorological conditions during the applications.

The spread factor (ratio of drop diameter to stain diameter) of the Futura tank mix formulation was determined over the drop size range (275

Table 2. Aircraft* and Meteorological Parameters.

Set	Date	Location	Pressure (kPa)	Height** (m)	Speed (km/hr)	Application Rate (L/ha)	Temperature (°C)	Wind Speed (km/hr)	RH (%)
A	May 29	Dewdrop Range	210	15	179	3.1	13	<3	58
B	May 21	Dewdrop Range	196	20	179	2.8	6	<3	86
C	May 23	Orchard Lake	158	20	179	2.8	5	0	100
D	May 26	Mt. Godreau	140	20	179	2.8	5	4.7	72
E	May 27	Paul Lake	175	20	179	3.1	9	0	64
F	May 27	Moulton Creek	210	20	179	3.1	14	0	60
G	May 28	Coyote Lake	210	20	179	3.1	6	0	80
H	May 29	Dewdrop Range	210	15	179	3.1	13	<3	58
I	May 28	Coyote Lake	210	20	179	3.1	6	0	80

*Cessna 188, Ag. Truck equipped with Micronair AU5000 nozzles.
**Approximate height above the forest canopy, the height of the forest canopy is approximately 25 m.

to 375 um) using a droplet generator (Slack 1984). The operation of the droplet generator is described more fully in the 1986 report (Wallace and Jahren 1987). Due to the high viscosity of the tank mix sample it was impossible to produce drops less than 275 um in diameter. The diameter of the falling droplets were determined and the resulting stain produced on blank Kromekote cards provided the necessary information to calibrate the spread factor.

The stains found on the Kromekote cards and water sensitive paper were sized and counted using a Cambridge Instruments Ltd. Quantimet 970 Image Analysis System. Two image frames were counted on each card. The total area counted was 10.6 cm^2 or two circles with a radius of 1.3 cm. In order to magnify the images to the greatest degree the camera was lowered such that one pixel represented 37.11 um.

A blue filter of optical density 40 was placed overtop of each card prior to counting. The filter enhanced the stains and allowed a direct image analysis. The cards were not photocopied as in last years work. The direct image analysis allowed a roundness factor of 1.25 to be used. The roundness factor takes into account the non-circular shape of some stains and at the above setting all the images in a frame were counted. The cutoff diameter chosen for the lowest class was 30 um (drop diameter), the limit of detection being 25 um (drop diameter). This represents a substantial lowering of the cutoff diameter over the 1986 report where 50 um was used.

The number of individual stains was counted and converted to drop diameter size classes using the spread factor. Usually the lowest size class was 30 to 45 um and the class width was kept at 15 um. The exceptions would be in a case where no droplets were present in that particu-

lar range. The upper limit on the size class ranged from 225 to 240 um. The number of drops and the volume (calculated using the mid-point) were accumulated by percent in each size class and the number and volume median diameters as well as the number of drops per cm^2 calculated. The calculations were performed using the Lotus 1-2-3 software package on an IBM-PC.

The results for each card were added together in order to obtain the overall results for each set. A graph of cumulative (volume or number) less than the stated drop diameter (upper class limit) was constructed as a pictorial representation of the distribution.

In order to calculate the range ($D_V0.9$ - $D_V0.1$) and the relative span (range ÷ $D_V0.5$) the size of drop at the 10 and 90 cumulative percent levels were recorded from the graphs, providing a measure of the heterogeneity of the droplet distribution.

Petri dish samples were analyzed for the amount of Rhodamine B dye, the actual dye content in the tank mix was 0.018%. The percent of B.t. in each application was either 67.7% or 75% for application rates of 3.1 and 2.8 L/ha respectively. From the B.t. to dye ratios one can calculate the amount of B.t. deposited in mg/m^2 or one could work in international units (IU). The potency of the formulated B.t. mixture was 11,536 IU/mg. Rhodamine B is photodegradable and a correction factor of 1.13 was applied which accounts for the photodegradation before pickup. The figure is an average of 30 agricultural drift trials conducted in Saskatchewan. The petri dish samples were analyzed using a model 204 Perkin Elmer Fluorescence Spectrophotometer. The system is equipped with an auto sampler, concentration readout unit, and a model 80 printer. The excitation and analyzer wavelength were 545 and 570 n.m. re-

spectively. The minimum detectable concentration was 0.1 parts per billion (ppb).

RESULTS

Table 3 gives a complete summary of the droplet sizing and recoveries (based on the cards). One note of caution here, must be that these recoveries are based on the volume of spray found on the cards. In a forest environment the small drops (30 to 50 um) will be filtered quite efficiently, therefore one would expect low recoveries as shown in Table 3. The "range" = ($D_V0.9$ - $D_V0.1$) gives the variation in particle size that encompasses 80% of the spray volume, and the relative span is this range divided by $D_V0.5$. The relative span is a nondimensional index related to the uniformity of the drop spectra. The smaller the relative span the more monodisperse the spectrum. Yates et al. (1983) outlines the ASTM definitions: relative span, range, $D_V0.1$, $D_V0.5$ and $D_V0.9$. The relative spans ranged from 0.8 to 1.3 indicating a slightly lower spray uniformity compared with the 1986 data.

The volume median diameter (VMD) for the eight sizings ranged from 96 to 211 um whereas in 1986 the range was 276 to 770 um. Similarly the number median diameters (NMD) have decreased substantially from 43 to 152 um in the 1986 study to <45 in the present case.

The coverage expressed as the number of drops per cm^2 has decreased over the 1986 data (2.7 to 19.1 drops per cm^2) compared to 1.3 to 5.7 drops per cm^2 in 1987.

The spread factor found for the Kromekote cards (0.67) compares favourably with that of Taylor (1974); he found a spread factor of 0.65 for drops of 130 um diameter.

Table 4 contains the deposit found from dye analysis of the petri dishes. The recoveries calculated from dye analysis are a more accurate method of deposit assessment compared to flat Kromekote card samples.

Table 3. Droplet Size Data (Kromekote Cards).

Set	Spread* Factor	VMD ($D_V0.5$) (microns)	NMD** (microns)	Recovery*** (%)	$D_V0.1$ (microns)	$D_V0.9$ (microns)	Relative Span	Drops per cm^2 (average)
A	0.67	140	<45	1.3	45	232	1.3	2.0
B	0.67	211	<45	6.3	100	224	0.6	2.2
B	0.46****	136	<45	3.2	45	190	1.1	5.7
C	0.67	138	<45	3.3	55	210	1.1	3.0
D	0.67	174	<45	2.4	62	233	1.0	1.6
E	0.67	175	<45	1.9	60	220	0.9	1.5
F	0.67	181	<45	2.4	80	222	0.8	1.8
G	0.67	96	<45	0.6	40	150	1.2	1.3

*Defined as the ratio of drop diameter to stain diameter.
**In all cases the number median diameter was less than 45 um, which represents the smallest upper class plotted.
***Based on conversion of stains to drops using 30 BIU/ha of B.t. as the standard application rate.
****Water sensitive paper.

Table 4. Petri Dish Analysis.

Trial	Number of Dishes	Mean Deposit (MIU/m^2)*	Mean Deposit (BIU/ha)**	Recovery*** (%)	Coefficient of Variation (%)
Dewdrop Range	24	1.17	11.7	39	39
Coyote Lake	19	0.17	1.7	6	83

*MIU/m^2 = Million International Units of B.t. per square metre. The petri dish area was 0.006 m^2.
**BIU/ha = Billion International Units of B.t. per hectare.
***Based on an application rate of 30 BIU/ha of B.t.

The cards are used mainly for VMD, NMD, and coverage density (number of drops per cm^2). The coefficient of variation (C of V) for the Dewdrop range was 39%, which was similar to agricultural aircraft trials where the C of V ranged from 35 to 46% for a Cessna AgWagon and a Piper Pawnee using conventional disc and core hydraulic nozzles (Maybank et al. 1978). Parkin et al. (1985) estimated the coefficient of variation for an Auster J5L Aiglet aircraft at ultra low volume (1 L/ha) and low volume (20 L/ha) application rates the results were 64% and 13% respectively.

Figure 1 shows the deposit found in drops per cm^2 versus position under the aircraft. The flying height was 15 m above the canopy at 179 km/hr and a blade angle of 30° on the Micronair AU5000 nozzles. The average cover density was 2 drops/cm^2. One should use a lane separation of approximately 25 m in order to obtain good coverage. The patterns may be overlapped and one can calculate when the lowest C of V is obtained by varying the lane separation (Quantick 1985).

Figures 2 through 9 show the plots of cumulative percent (by volume and number) less than the stated drop diameter. Tables 5 through 12 tabulate the calculations necessary to construct the graphs. Each table and figure corresponds to Sets A through G (Table 2). The overall results are found in Table 3.

The petri dish analysis is given in Tables 13 and 14, the results are expressed in terms of ug of B.t. and Million International Units of B.t. per square metre (MIU/m^2).

Appendix I contains the detailed droplet counts for each card set.

Figure 1.

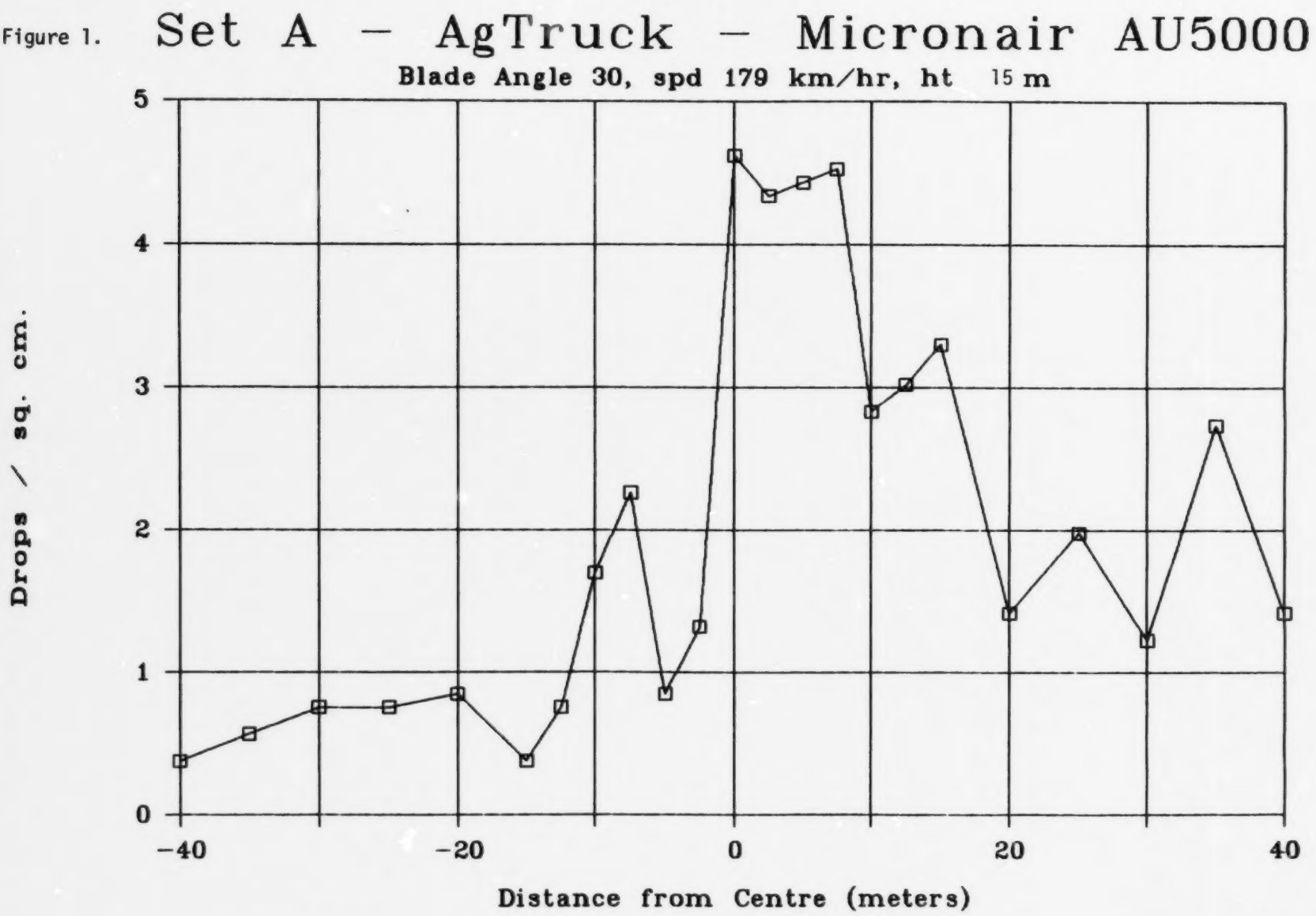
Set A – AgTruck – Micronair AU5000
Blade Angle 30, spd 179 km/hr, ht 15 m
Drops / sq. cm.
0
1
2
3
4
5
−40
−20
0
20
40
Distance from Centre (meters)

Table 5. Spray Image Set - A Dewdrop Calibration

Diam. class (microns)	Count	Acc. % (by no.)	Volume (microl.)	Acc. % (by vol)
30 - 45	384	78.0	0.0106	9.5
75 - 90	63	90.9	0.0185	26.2
105 - 120	24	95.7	0.0179	42.3
120 - 135	6	97.0	0.0065	48.2
150 - 165	6	98.2	0.0123	59.2
165 - 180	1	98.4	0.0027	61.6
180 - 195	1	98.6	0.0035	64.7
195 - 210	2	99.0	0.0087	72.5
210 - 225	2	99.4	0.0108	82.2
225 - 240	3	100.0	0.0197	100.0
	492		0.1112	

No. median diam. = 45
Vol. median diam. = 140

Drops/sq. cm. = 2.02

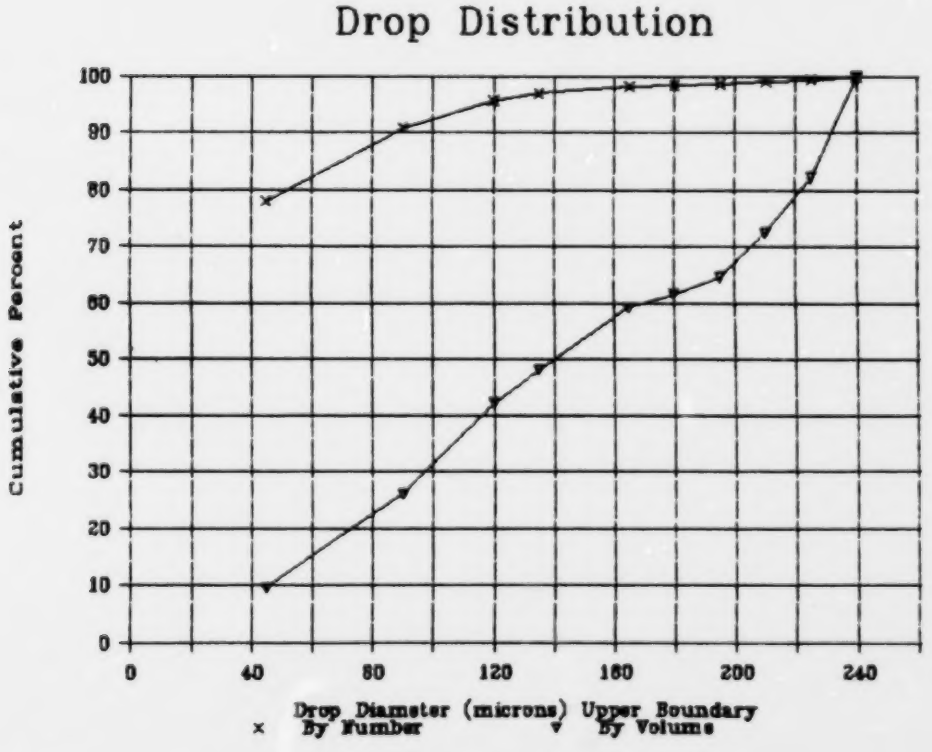

Figure 2. Drop Distribution Dewdrop Calibration Run.

Table 6. Spray Image Set - B Dewdrop Kromekote Cards

Diam. class (microns)	Count	Acc. % (by no.)	Volume (microl.)	Acc. % (by vol)
30 - 45	19	55.9	0.0005	1.7
75 - 90	5	70.6	0.0015	6.6
105 - 120	4	82.4	0.0030	16.5
150 - 165	1	85.3	0.0020	23.2
165 - 180	1	88.2	0.0027	32.1
195 - 210	1	91.2	0.0043	46.5
210 - 225	3	100.0	0.0162	100.0
	34		0.0302	

No. median diam. = 45
Vol. median diam. = 211

Drops/sq. cm. = 2.14

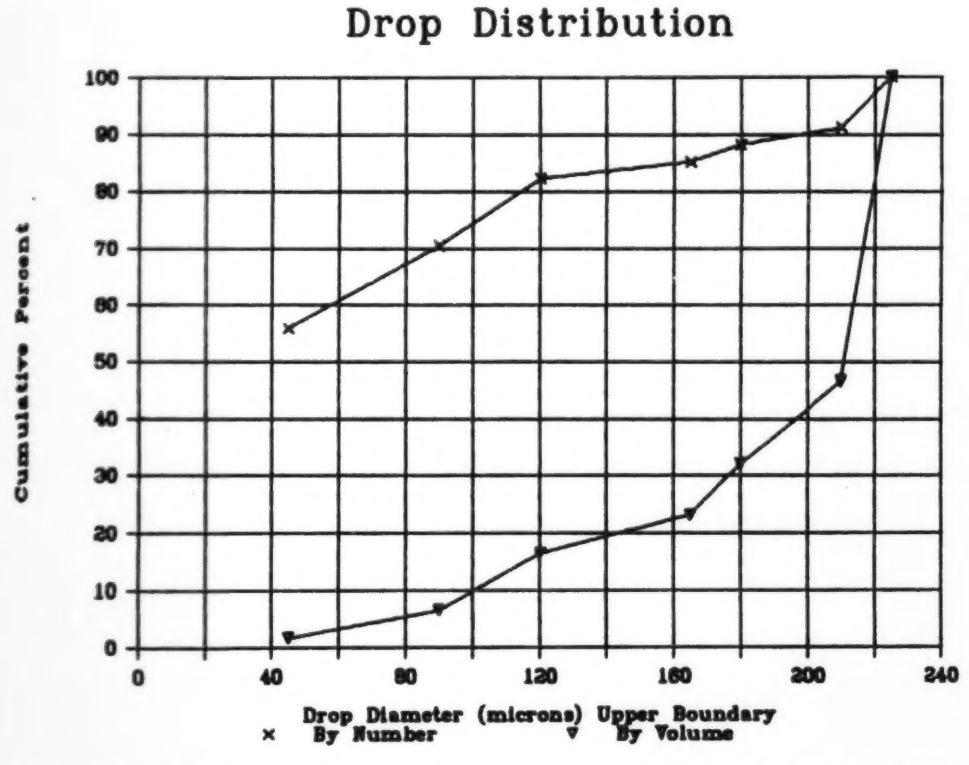

Figure 3. Drop Distribution-Dewdrop Calibration - Kromekote Cards.

Table 7. Spray Image Set - B Dewdrop - Water Sensitive Cards

Diam. class (microns)	Count	Acc. % (by no.)	Volume (microl.)	Acc. % (by vol)
30 - 45	57	62.6	0.0016	10.4
60 - 75	30	95.6	0.0048	42.3
120 - 135	1	96.7	0.0011	49.5
135 - 150	1	97.8	0.0015	59.5
165 - 180	1	98.9	0.0027	77.2
180 - 195	1	100.0	0.0035	100.0
	91		0.0151	

No. median diam. = 45
Vol. median diam. = 136

Drops/sq. cm. = 5.72

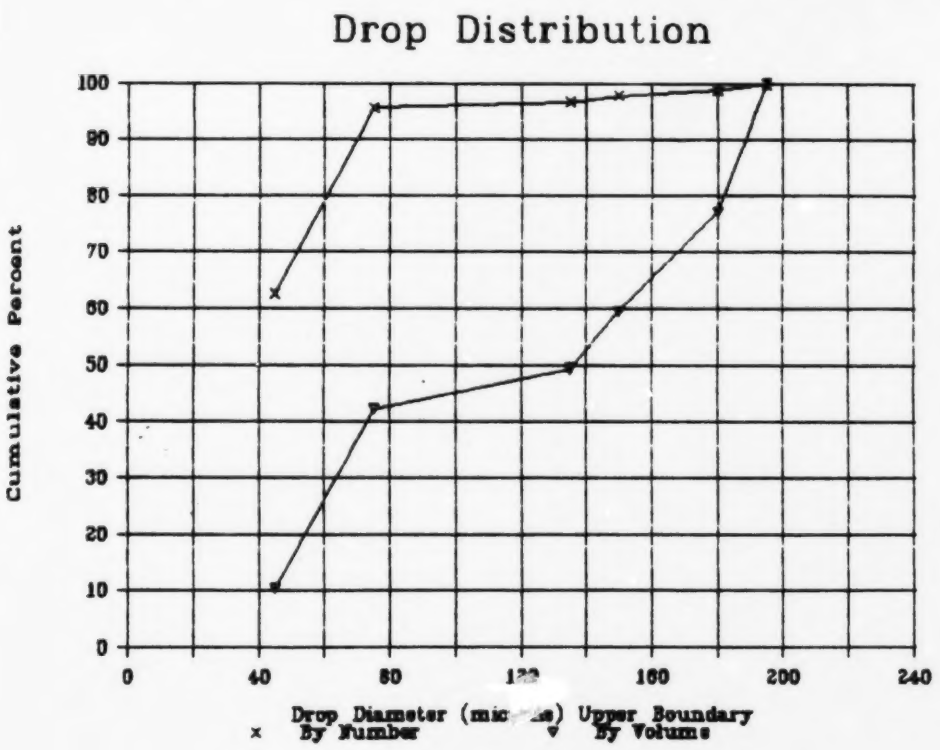

Figure 4. Drop Distribution Dewdrop Calibration - Water Sensitive Paper.

Table 8. Spray Image Set - C Orchard Lake

Diam. class (microns)	Count	Acc. % (by no.)	Volume (microl.)	Acc. % (by vol.)
30 - 45	97	61.8	0.0027	4.9
75 - 90	37	85.4	0.0109	35.0
105 - 120	7	89.8	0.0052	34.7
120 - 135	7	94.3	0.0076	48.7
150 - 165	4	96.8	0.0082	63.8
165 - 180	2	98.1	0.0054	73.7
180 - 195	1	98.7	0.0035	80.1
210 - 225	2	100.0	0.0108	100.0
	157		0.0542	

No. median diam. = 45
Vol. median diam. = 138

Drops/sq. cm. = 2.96

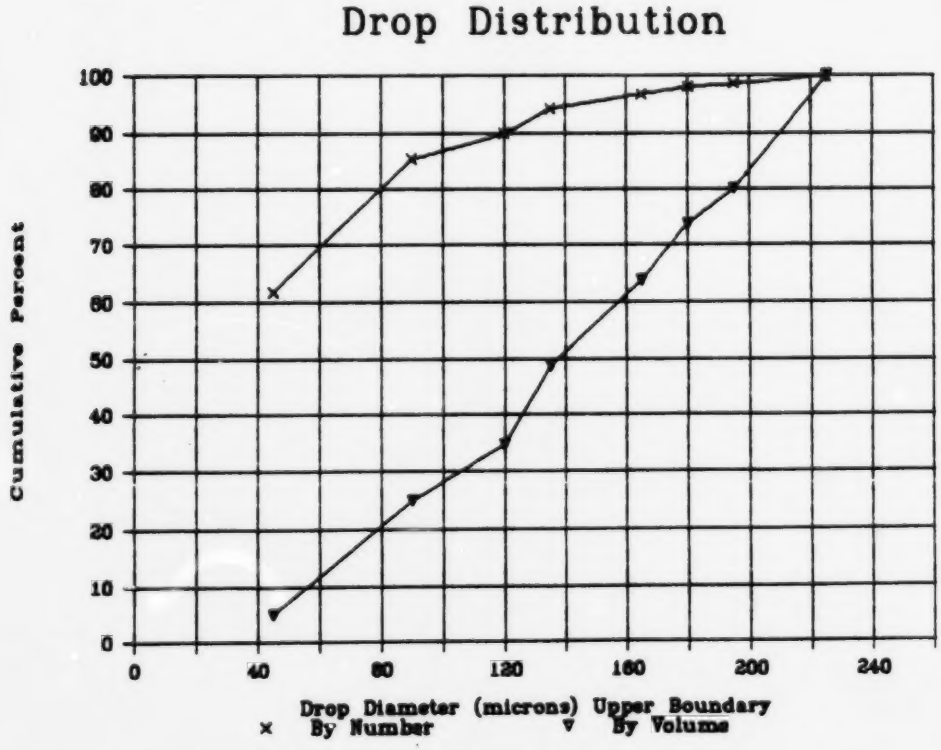

Figure 5. Drop Distribution Orchard Lake.

Table 9. Spray Image Set - D Mt. Godreau

Diam. class (microns)	Count	Acc. % (by no.)	Volume (microl.)	Acc. % (by vol)
30 - 45	40	58.8	0.0011	3.6
75 - 90	16	82.4	0.0047	18.9
105 - 120	6	91.2	0.0045	33.4
120 - 135	2	94.1	0.0022	40.4
150 - 165	1	95.6	0.0020	47.1
195 - 210	1	97.1	0.0043	61.2
210 - 225	1	98.5	0.0054	78.6
225 - 240	1	100.0	0.0066	100.0
	68		0.0308	

No. median diam. = 45
Vol. median diam. = 174

Drops/sq. cm. = 1.60

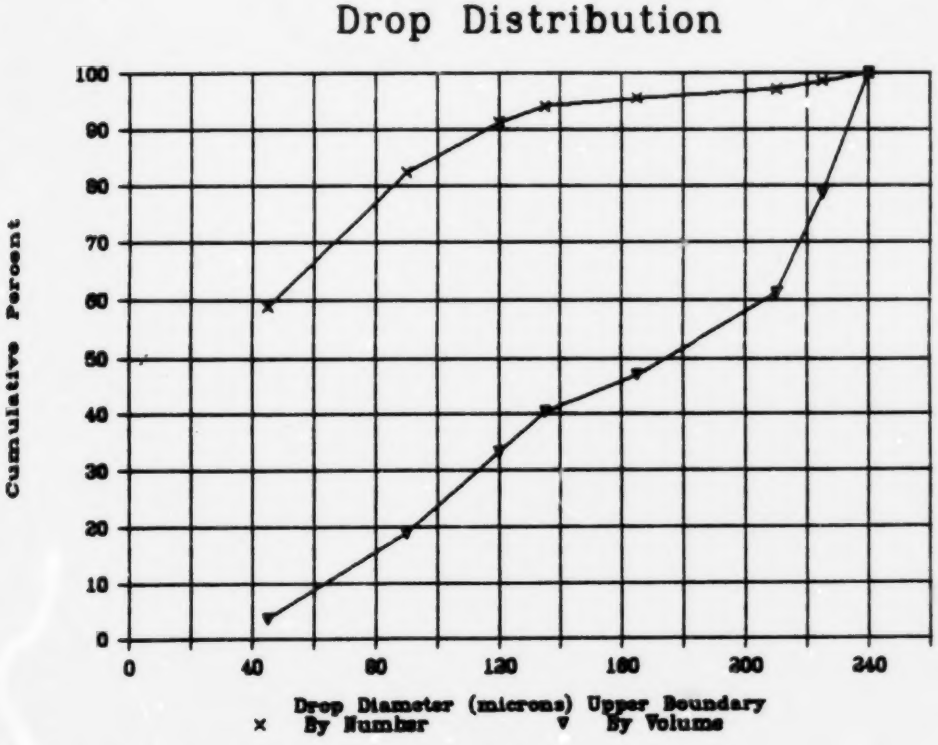

Figure 6. Drop Distribution Mt. Godreau.

Table 10. Spray Image Set - E Paul Lake

Diam. class (microns)	Count	Acc. % (by no.)	Volume (microl.)	Acc. % (by vol)
30 - 45	27	58.7	0.0007	3.7
75 - 90	12	84.8	0.0035	21.3
105 - 120	3	91.3	0.0022	32.5
120 - 135	1	93.5	0.0011	37.9
165 - 180	1	95.7	0.0027	51.4
195 - 210	1	97.8	0.0043	73.1
210 - 225	1	100.0	0.0054	100.0
	46		0.0200	

No. median diam. = 45
Vol. median diam. = 175

Drops/sq. cm. = 1.45

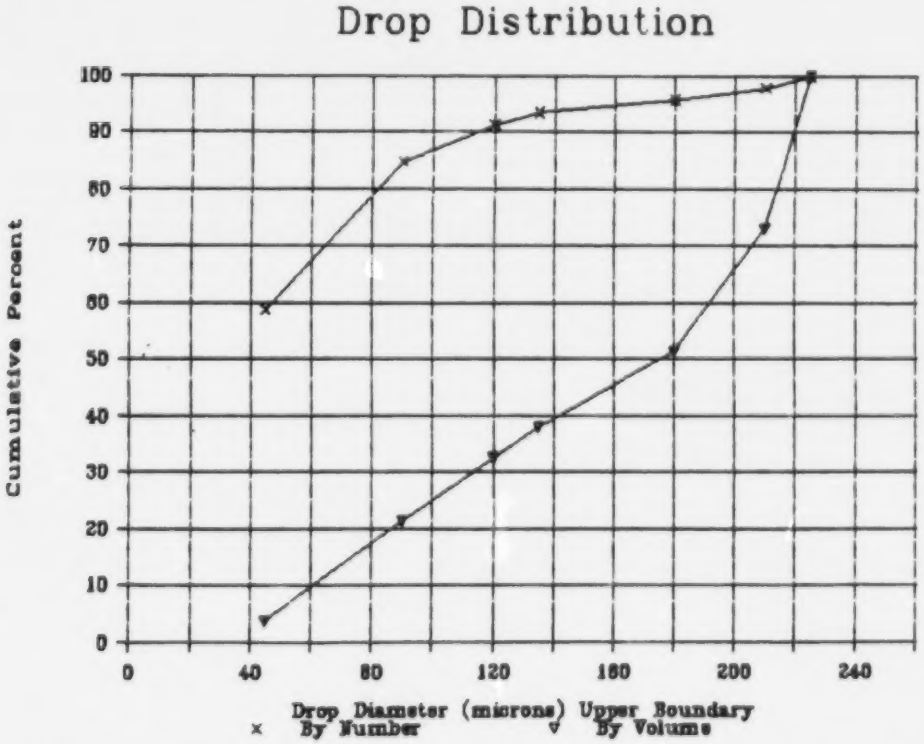

Figure 7. Drop Distribution Paul Lake.

Table 11. Spray Image Set - F Moulton Creek

Diam. class (microns)	Count	Acc. % (by no.)	Volume (microl.)	Acc. % (by vol)
30 - 45	38	67.9	0.0010	4.1
75 - 90	7	80.4	0.0021	12.0
105 - 120	6	91.1	0.0045	29.4
150 - 165	1	92.9	0.0020	37.3
165 - 180	1	94.6	0.0027	47.7
180 - 195	2	98.2	0.0069	74.5
225 - 240	1	100.0	0.0066	100.0
	56		0.0258	

No. median diam. = 45
Vol. median diam. = 181

Drops/sq. cm. = 1.76

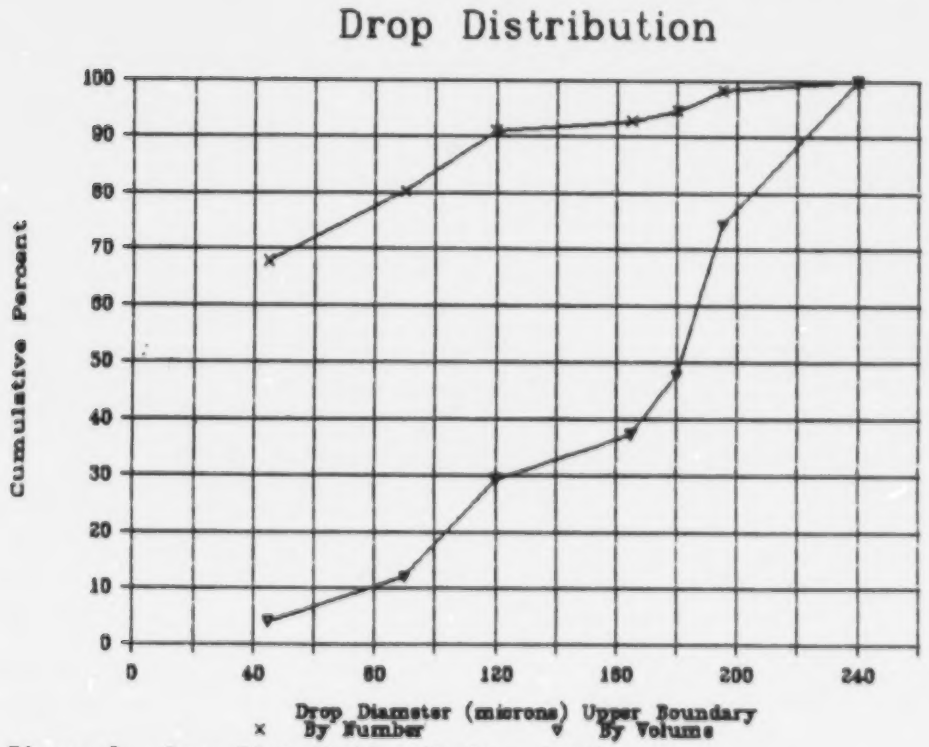

Figure 8. Drop Distribution Moulton Creek.

Table 12. Spray Image Set - G **Coyote Lake**

Diam. class (microns)	Count	Acc. % (by no.)	Volume (microl.)	Acc. % (by vol)
30 - 45	31	75.6	0.0009	13.3
75 - 90	7	92.7	0.0021	45.2
105 - 120	2	97.6	0.0015	68.3
150 - 165	1	100.0	0.0020	100.0
	41		0.0065	

No. median diam. = 45
Vol. median diam. = 96

Drops/sq. cm. = 1.29

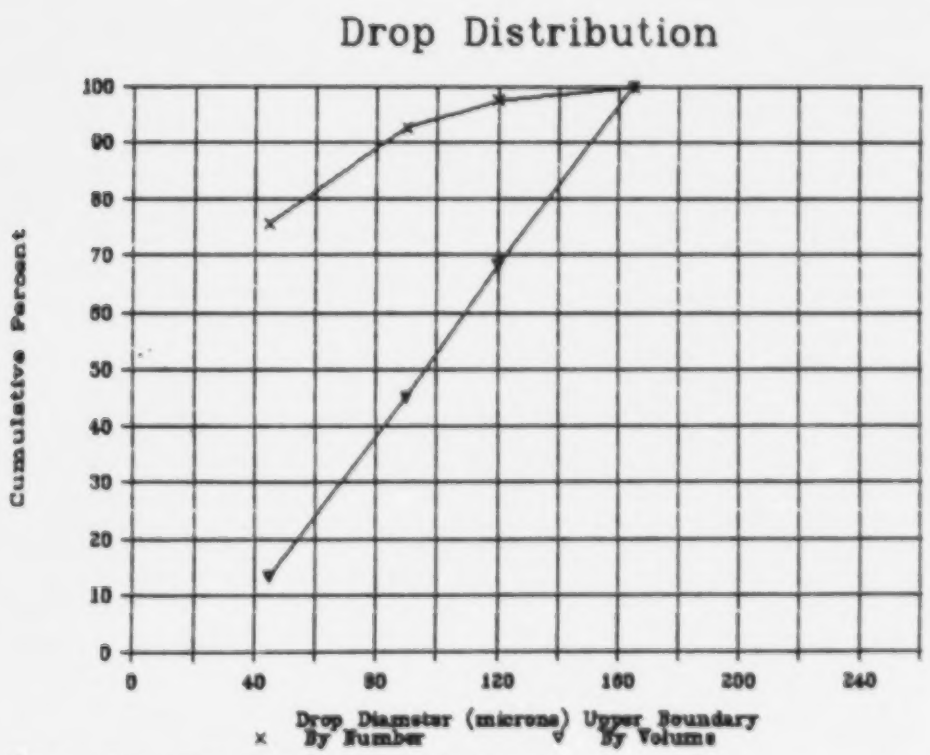

Figure 9. Drop Distribution Coyote Lake.

SAMPLE
SET
H

Table 13. PETRI DISH ANALYSIS DEWDROP RANGE

DISH NO.	PPB	BLANK	ug Bt	I.U./DISH	MIU/M^2
A1	7.90	0.02	673.74	7774.96	1.30
B1	6.30	0.02	536.94	6196.29	1.03
C1	10.30	0.02	878.94	10142.97	1.69
A2	7.80	0.02	665.19	7676.29	1.28
B2	10.40	0.02	887.49	10241.63	1.71
C2	11.80	0.02	1007.19	11622.97	1.94
A3	6.90	0.02	588.24	6788.29	1.13
B3	8.70	0.02	742.14	8564.30	1.43
C3	6.00	0.02	511.29	5900.29	0.98
A4	7.40	0.02	630.99	7281.62	1.21
B4	4.80	0.02	408.69	4716.28	0.79
C4	5.10	0.02	434.34	5012.28	0.84
A5	4.20	0.02	357.39	4124.28	0.69
B5	3.70	0.02	314.64	3630.95	0.61
C5	6.80	0.02	579.69	6689.62	1.11
A6	1.70	0.02	143.64	1657.61	0.28
B6	3.00	0.02	254.79	2940.28	0.49
C6	7.40	0.02	630.99	7281.62	1.21
A7	7.50	0.02	639.54	7380.29	1.23
B7	12.50	0.02	1067.04	12313.64	2.05
C7	8.50	0.02	725.04	8366.96	1.39
A8	4.40	0.02	374.49	4321.61	0.72
B8	6.70	0.02	571.14	6590.96	1.10
C8	12.00	0.02	1024.29	11820.31	1.97
		MEAN	610.33	7043.18	1.17
		STD DEV	238.63	2753.84	0.46
		C of V%	39.10	39.10	39.10

SAMPLE
SET
I

Table 14. PETRI DISH ANALYSIS COYOTE LAKE

DISH NO.	PPB	BLANK	ug Bt	I.U./DISH	MIU/M^2
E1	3.18	0.02	270.18	3117.88	0.52
E2	0.36	0.02	29.07	335.47	0.06
E3	2.15	0.02	182.12	2101.61	0.35
E4	1.83	0.02	154.76	1785.87	0.30
E8	2.32	0.02	196.65	2269.34	0.38
E11	0.78	0.02	64.98	749.87	0.12
E12	0.66	0.02	54.72	631.47	0.11
E13	0.23	0.02	17.96	207.20	0.03
E14	0.19	0.02	14.54	167.73	0.03
E15	0.22	0.02	17.10	197.33	0.03
E16	0.36	0.02	29.07	335.47	0.06
E18	0.78	0.02	64.98	749.87	0.12
E21	0.48	0.02	39.33	453.87	0.08
E22	0.40	0.02	32.49	374.93	0.06
E23	0.55	0.02	45.32	522.94	0.09
E26	1.15	0.02	96.62	1114.94	0.19
E28	1.68	0.02	141.93	1637.87	0.27
E30	1.61	0.02	135.95	1568.81	0.26
	MEAN		88.21	1017.91	0.17
	STD DEV		72.76	839.70	0.14
	C of V%		82.49	82.49	82.49

NOTE: DATA POINT · E6 OMITTED

DISCUSSION

The drop frequency found from the 1986 spray trials (2.7 to 19.1 drops/cm^2) was somewhat higher than that found for 1987 (1.3 to 5.7 drops/cm^2). Several factors are responsible for the reduced ground deposit. The application rates for the fixed wing AgTruck were lowered from 6 to 2.8 to 3.1 L/ha from 1986 to 1987. The fly heights were increased in 1987 to 15 to 22 m above the canopy whereas in 1986 the height was 9.1 m for the fixed wing aircraft. The average VMD from 1986 to 1987 dropped by almost a factor of 2 from 290 to 150 um respectively. The smaller droplet spectrum would have a better catch efficiency on the fir needles and this might result in a lower ground deposit. Joyce and Spillman (1979) point out the droplets which contribute the highest dose to larvae, buds and pine needles are the smallest size fraction (30 to 50 um). A larger VMD would only contribute to a greater proportion of droplets landing on the forest floor.

The water sensitive cards did not compare well with Kromekote cards. Most of the water sensitive cards turned green due to the high relative humidity and those that were sized tended to have elongated stains compared to Kromekote card stains. Water sensitive cards with a smoother surface (photographic paper) might prove better.

The assessment of coverage should be focussed more at the Douglas fir needles. The mode of action of B.t. against the western spruce budworm is via ingestion allowing the bacteria to act as a gut poison. Quantick (1985) points out that droplets of 100 um have a good chance of being caught on a smooth stem of 3 mm diameter. Factors such as serrated edges, or hairs will increase the catch efficiency of these droplets (Quantick 1985). The size of our target, the Douglas fir needle,

is in the order of 25 mm long and approximately 1 mm wide. An aqueous spray of B.t. that contains a large number of droplets in the 30 to 50 um range with an evaporation suppressant should be effective in depositing on the fir needles.

The rate of removal of spray drops through a forest canopy depends on the size of collectors and on the droplet size spectrum. Smaller drops will penetrate further than large drops, and under turbulent conditions small drops will be filtered by the forest canopy more effectively than over bare ground. The turbulent dispersal of droplets occurs when the average speed of the turbulent eddies is larger than the fall velocity of droplets. It can be shown that in a forest with trees 20 m in height and a wind speed 10 m above the trees of 2 m/sec the average speed of the eddies is 0.57 m/sec. The conditions described above would allow droplets of smaller than approximately 160 um to be dispersed largely by turbulence rather than sedimentation.

The choice of the most appropriate sampler for evaluation of deposit in the forest situation would have the following characteristics: situated in the canopy at several heights, and have a diameter of approximately 1 mm, similar to a fir needle. Sundaram et al. (1986) have used a coiled aluminum wire of 0.75 mm diameter located at several heights within a coniferous tree. The authors found a linear relationship between deposits on needles and on wire. In the same report the authors found poor correlation between simulated and live foliage deposits compared with ground deposits on glass slides and Kromekote cards. The flat card is not a good collector of droplets and becomes worse as the wind speed increases. Petri dishes are not much better although one can analyze the amount of dye to obtain a deposit value. An alternative

is the rotorod sampler. The rotorod sampler spins at a fixed speed, slicing a known volume of air per unit time. The arms are 1.5 mm wide which is similar in size to a fir needle. The arms can be washed off to provide a measure of the spray cloud conditions. If the wind speed is calm the rotorod sampler still samples at a constant speed but would not be sampling isokinetically (i.e. at the same speed as the wind).

RECOMMENDATIONS

1. The use of an inert wire (plastic or metal) of approximately 1 mm diameter located in the canopy would best simulate the deposition on fir needles. It is best to use an inert material, as alcohol is the extraction liquid and contamination may occur if natural needles are used.

2. Spray under conditions of light winds, 1 to 3 m/sec (3.6 to 10.8 km/hr) so that dispersion of droplets occurs by turbulence rather than sedimentation.

3. Continue to use Kromekote cards and petri dishes for comparison purposes and use Rhodamine B at 0.02% in tank mixes as a fluorescent tracer both for petri dishes and simulated needle samplers. In this way a deposit can be calculated and related to the amount of B.t. per area.

4. The use of a rotorod sampler would help in tracing the spray cloud. Several of these samplers could be used on an experimental basis.

5. Continue to use the Micronair AU5000 nozzles and where possible try to reduce the release height above the canopy, while maintaining a safe margin for aircraft operation.

REFERENCES

Barry, J.W., W.M. Ciesla, M. Tysowsky Jr. and R.B. Ekblad. 1977. Impaction of Insecticide Particles on Western Spruce Budworm Larvae and Douglas Fir Needles. J. Econ. Entomol. 70(3):387-388.

Joyce, R.J.V. and J.J. Spillman. 1979. Discussion of Aerial Spraying Techniques. In: Control of Pine Beauty Moth by Fenitrothion in Scotland, 1978 (eds. A.V. Holden and D. Bevan). Occasional Paper No. 4, pp. 13-24, Forestry Commission.

Maclauchlan, L.E., I.K. Smith and R.F. Hodgkinson. 1987. Kamloops Forest Region Western Spruce Budworm Project. Forest Service Internal Report.

Maybank, J., K. Yoshida, S.R. Shewchuk and R. Grover. 1978. Spray Drift of Aerially-Applied Herbicide: Report of the 1977 Field Trials. Saskatchewan Research Council Publication No. P-78-2.

Parkin, C.S., J. Outram, A.J. Last and A.P.W. Thomas. 1985. In Application and Biology Monograph No. 28 Ed. E.S.E. Southcombe. Proc. Symp. of University of Reading, Berkshire, England. pp. 211-220.

Quantick, H.R. 1985. Aviation in Crop Protecting Pollution and Insect Control. Collins Professional and Technical Books, 8 Grafton Street, London, England. pp. 264-270.

Slack, W.E. 1984. The National Aeronautical Establishment Droplet Generator. Proc. Symp. on the Future Role of Aviation in Agriculture. Saskatoon, Saskatchewan. April 1984. pp. 331-343.

Sundaram, K.M.S., A. Sundaram and R. Nott. 1986. Mexacarbate Deposits on Simulated and Live Fir Needles During an Aerial Spray Trial. Trans. ASAE 29(2):382-388.

Taylor, P.A. 1974. Research Into Aerial Spraying of Agricultural Chemicals. Proc. of Agric. Eng. Conf., Sydney, Australia.

Wallace, K.W. and R. Jahren. 1987. An Assessment of Kromekote Card Deposits from Aerial Spray Applications. Saskatchewan Research Council Technical Report No. 193, Publication No. E-906-1-B-87.

Yates, W.E., R.E. Cowden and N.B. Akesson. 1983. Nozzle Design Influence on Uniformity of Droplet Size Spectrums from Agricultural Aircraft. Trans. ASAE 26(6):1633-1637.

APPENDIX I

RAW COUNT DATA

Dew Drop Jumo Card Reference

Diam. class (microns)	Centre	R2.5	R5.0	R7.5	R10.0	R12.5	R15.0	R20.0	R25.0	R30.0	R35.0	R40.0	L2.5	L5.0	L7.5	L10.0	L12.5	L15.0	L20.0	L25.0	L30.0	L35.0	L40.0
15 - 30	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
30 - 45	31	35	36	38	27	28	30	11	18	13	23	13	8	7	19	15	7	3	3	5	5	6	3
45 - 60	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
60 - 75	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
75 - 90	12	7	4	6	1	3	4	2	2	0	5	1	3	1	4	2	1	0	4	0	1	0	0
90 - 105	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
105 - 120	4	1	4	4	1	0	0	2	1	0	0	0	1	0	0	0	0	0	2	1	2	0	1
120 - 135	0	1	2	0	1	0	0	0	0	0	0	0	0	0	0	1	0	1	0	0	0	0	0
135 - 150	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
150 - 165	1	0	0	0	0	1	1	0	0	0	0	1	0	1	0	0	0	0	0	1	0	0	0
165 - 180	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0
180 - 195	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
195 - 210	1	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
210 - 225	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
225 - 240	0	1	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	1	0	0	0
No. drops/sq. cm.	4.62	4.34	4.43	4.53	2.83	3.02	3.30	1.42	1.98	1.23	2.74	1.42	1.32	0.85	2.26	1.70	0.75	0.38	0.85	0.75	0.75	0.57	0.38

Kromecote Cards

Diam. class (microns)	Location KR2.5	KL2.5	KL5.0
30 - 45	8	1	10
75 - 90	2	1	2
105 - 120	2	2	0
150 - 165	1	0	0
165 - 180	0	0	1
195 - 210	0	0	1
210 - 225	1	1	1
No. drops/sq. cm.	2.64	0.94	2.83

Watersensitive Cards

Diam. class (microns)	Location WR2.5	WL2.5	WL5.0
30 - 45	23	24	10
60 - 75	8	15	7
120 - 135	1	0	0
135 - 150	0	0	1
165 - 180	0	1	0
180 - 195	0	1	0
No. drops/sq. cm.	6.04	7.74	3.40

Orchard Lake Cards

Diam. class (microns)	Location F5	F6	F7	F9	F11
30 - 45	12	14	20	30	21
75 - 90	3	4	8	15	7
105 - 120	1	3	0	2	1
120 - 135	0	1	2	3	1
150 - 165	0	2	0	0	2
165 - 180	0	1	0	0	1
180 - 195	0	0	1	0	0
210 - 225	0	0	1	0	1
No. drops/sq. cm.	1.51	2.36	3.02	4.72	3.21

Mt. Godreau Cores

Diam. class (microns)	Location B7	B9	B15	B23
30 - 45	4	12	12	12
75 - 90	3	6	4	3
105 - 120	0	1	3	2
120 - 135	0	0	2	0
150 - 165	0	0	1	0
195 - 210	0	0	1	0
210 - 225	0	1	0	0
225 - 240	0	1	0	0
No. drops/sq. cm.	0.66	1.98	2.17	1.60

Paul Lake Cards

Diam. class (microns)	Location PLP-01	PLP-10	PLP-27
30 - 45	0	20	7
75 - 90	2	8	2
105 - 120	1	2	0
120 - 135	0	1	0
165 - 180	0	1	0
195 - 210	1	0	0
210 - 225	1	0	0
No. drops/sq. cm.	0.47	3.02	0.85

Moulton Creek Cards

Diam. class (microns)	Location 2K1	2K5	2K8
30 - 45	17	12	9
75 - 90	1	3	3
105 - 120	1	3	2
150 - 165	0	0	1
165 - 180	0	1	0
180 - 195	1	1	0
225 - 240	0	1	0
No. drops/sq. cm.	1.89	1.38	1.42

Coyote Lake Cards

Diam. class (microns)	Location E6	E10	E18
30 - 45	16	11	4
75 - 90	0	4	3
105 - 120	0	2	0
150 - 165	0	1	0
No. drops/sq. cm.	1.51	1.70	0.66